

Survival, Growth and *Orygmophora mediofoveata* Shoot Borer Attack of *Nauclea diderrichii* Progenies Established in Three Ecological Zones in Ghana

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Nauclea diderrichii is a tropical African hardwood species and a suitable candidate for plantation development. However, attack by the *Orygmophora mediofoveata*, Hamps shoot borer threatens establishment of the species in plantations. A genotype * environment assessment of 15 *N. diderrichii* progenies from Ghana and Togo was conducted in the Wet Evergreen, Moist Semi-deciduous and Dry Semi-deciduous forest zones. Progeny performance (Attack intensity, survival and growth) varied significantly between sites, and marginally within sites after 2.7 years. Overall, incidence of shoot borer attack was lower at the wet zone than at the moist or dry zones. Percent survival was higher at the wet (79.5%) than at the moist (50.8%) or dry (55.0%) forest zones. Mean height across the 15 progenies was 5.40 m, 4.30 m, and 2.73 m at the wet, dry and moist forests, respectively. Similarly, mean diameter was 5.31 cm, 4.58 cm, and 2.83 cm at the wet, dry and moist zones, respectively. The relatively low growth rate recorded at the moist zone was attributed to the paucity of soil conditions at the experimental site. Three wet forest zone progenies (BS9, BS3 and BS2) and two moist forest zone progenies (BE2 and GA1) performed better than average and have been recommended for planting.

Keywords: Genotype * Environment Assessment; *Nauclea diderrichii*; *Orygmophora mediofoveata*; Growth Rates; Survival Rate; Ghana; Togo

Introduction

Nauclea diderrichii (*Sarcocephalus diderrichii* De Wild) is a tropical African hardwood species belonging to the family Rubiaceae. The species is widely distributed across tropical Africa, from Liberia eastward through the Congo Basin to Uganda and Angola. It is a moderately fast-growing species, with fairly high density timber and durable wood. The tree grows up to about 60 m in height, with straight, cylindrical bole clear to 30 - 40 m, and trunk diameter ranging from 1.0 - 2.5 m. Its natural habitat is subtropical or tropical moist lowland forests. As a sun-loving species, the plant regenerates abundantly in gaps and openings and is often almost gregarious in the transition zone between freshwater swamps and lowland forests (Hawthorne, 1995). Young trees are often found in secondary bushy growth in humid areas.

The straight monopodial growth habit of this species has promoted interest in it for the production of transmission poles, veneers and timber for heavy construction, flooring and furniture. In recent years, *N. diderrichii* has been planted in high rainfall areas (2000 - 4500 mm) throughout West Africa, but

especially in south-east Nigeria. The biophysical limits for the growth of *Nauclea diderrichii* are; altitude 0 - 500 m; mean annual rainfall 1600 - 3000 mm; and mean annual temperature 24°C - 30°C. It does not grow well on excessively wet soils or on lateritic ones that dry out completely in the dry season.

In Ghana, the species is found in both the deciduous and evergreen forest zones. It is found at constant low densities and is never very abundant (Hawthorne, 1995). *Nauclea* is considered vulnerable (1994 IUCN threat category) due to its excessive exploitation (Hawthorne, 1995). It has been awarded a scarlet star for Ghana which means that it is common but under profound pressure from heavy exploitation (Hawthorne, 1995). In year 2000, an opportunity was created to increase the planting of *N. diderrichii* in Ghana when the species was selected as one of the five priority indigenous species for the national forest plantation development project. Selection of the five priority species was based on several factors including fast growth rate and low susceptibility to pest attacks. However, the vulnerability of *Nauclea* to opepe shoot borer *Orygmophora mediofoveata* (Lepidoptera: Noctuidae) was grossly underestimated. Not long after the project was started, considerable *O. mediofoveata* damage was recorded in several nurseries in the Eastern and

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Ashanti Regions, including two owned by the Forestry Research Institute (FORIG) at Mesewam and Fumesua near Kumasi (Bosu, et al., 2004).

Orygmophora mediofoveata attacks in *N. diderrichii* plantations were observed in Nigeria as far back as the 1930s. However, the identity of the borer was not discovered until 1962 when Eidt (1965a) reared the moth for the very first time. The damage caused by the shoot borer is principally through stunting of the trees in nursery transplant beds, and is rare in seed beds. Attack results in the rapid formation of a callus tissue over the injured parts, and may lead to mortality in heavy multiple attacks. Parry (1956) noted that “attack by *Orygmophora mediofoveata* was not severe enough to discourage use of the tree in pure plantations in Nigeria, but in Ghana, Opepe is so badly damaged that it is an unreasonable risk as a plantation crop”.

The life history of *Orygmophora mediofoveata* is generally unknown, particularly in the egg stage and the first instar larvae (Eidt, 1965b). The larvae which attack and damage the plants are grub-like and morphologically quite unusual. The larva is short and stout; the head is partly withdrawn into the prothorax and the legs and prolegs are well developed. Fully grown larvae of the ultimate instar are about 14mm long, and average head width is about 1.5 mm. Early instar larvae are translucent and appear greenish because of the plant tissue in the gut. Ultimate instar larvae are deep red on the dorsum but remain green on the venter. They infest the terminal shoots, boring in the last two or three internodes, and preferring the more apical shoot. They do not girdle the shoots, but bore in the pith and produce galleries several inches long. In the cause of tunneling, the larvae eject dark brown frass which accumulates in the leaf axils. This tunneling can reveal their presence. Pupation occurs within the galleries although there is no cocoon. The pupal period lasts about 3 weeks. However, the length of a generation is unknown and has been estimated to be about three or four months.

To minimize the impact of the shoot borer in *N. diderrichii* plantations, mixed-species planting trials were conducted, which showed some promise (Addo-Danso, et al., 2012). However, planting genetic strains inherently resistant to *O. mediofoveata* could be a more effective way of minimizing the impact of this endemic pest on its *N. diderrichii* host. In this study, we examined the susceptibility of fifteen *N. diderrichii* progenies from Ghana and Togo to *O. mediofoveata* shoot borer attack and its impact on the survival and growth of the plant in three forest zones.

Table 1.
Characteristics of ecological zones and number of accessions collected.

Forest zone	Rainfall (mm)	Country	Population	Population code	No. of progenies
Moist/Wet evergreen	1750 - 2000	Ghana	Benso	BS	3
Moist semi-deciduous, southeast	1500 - 1800	Ghana	Amantia	AM	2
Moist semi-deciduous, southeast	1200 - 1800	Ghana	Begoro	BE	2
Moist semi-deciduous, northwest	1200 - 1800	Ghana	Gambia village	GA	4
Moist semi-deciduous, plateau region	1200 - 1800	Togo	Badou	TG	3
Dry semi deciduous	1250 - 1500	Ghana	Berekum	BR	1

Materials and Methods

Seed Collection

Seeds were collected from trees in the *N. diderrichii* distribution range in Ghana and Togo. In Ghana, the seeds were obtained from three mother trees in the Wet Evergreen Forest zone (WEF), eight trees in the Moist Semi-deciduous Forest zone (MSF) and one tree from the Dry Semi-deciduous Forest zone (DSF). Seeds from Togo, were collected from threetrees in the Plain of Litimé (Table 1).

Seeds of all 15 progenies were sent to Mesewamnursery where they were processed for germination and seedling production. As *N. diderrichii* seeds are very small and photoblastic, seed germination was done in plastic bowls (45 cm diameter and 12 cm deep) placed in a shade house of about 50% radiation and watered regularly until germination occurred. Seeds took an average of 6 - 8 weeks to germinate, and were then transferred to plastic bags until used.

Establishment of G * E Plots

Standard genotype by environment (G * E) experiments involving 15 *Nauclea diderrichii* progenies were established in three ecological zones namely, WEF, MSF and DSF zones. The WEF plot was established inside the Nueng Forest Reserve near Benso in the Western Region (5°16'N, 1°89'W). The MSF plot was established at the FORIG nursery area at Mesewam (6°44'N, 1°30'W), near Kumasi in the Ashanti Region. The DSF plot was established inside the Afram Headwaters Forest Reserve near Abofour, also in the Ashanti Region (7°10'N, 1°40'W). On each site, the plots were established using four blocks each consisting of 15 progenies, with each progeny replicated 10 times per block, using a Randomized Complete Block Design (RCBD). All three trials were established in April 2008. The plots were maintained by regular weeding, and monitored for a period of three months during which beating-up was done with seedlings from the original stock.

Assessment of Plots

Assessments of the plots for incidence of the shoot borer attack, seedling survival, and growth rates (height and diameter) were carried out between 4 - 6 months intervals, from August 2008 to December 2010. Except for the December 2010 (age 2.7 years) assessment at which diameter was measured at breast height (dbh = 1.3 m), all previous measurements were carried

out at 10 cm above the soil level. Shoot borer attack intensity was ranked on a scale of 1-5; with 1 indicating no visible damage and 5 indicating severely damaged.

Data Analyses

Two factorial analyses of variance were used to estimate average differences in the variables (height, diameter and attack) using progeny and site as the main factors. Percentage data (survival) were arcsine transformed to conform to normality prior to analysis of variance.

Family heritability was estimated based on variance components obtained from analysis of variance as described by Zobel and Talbert (1991). The least square mean values were transformed to percentage deviation from the trial mean and were further multiplied by the heritability to provide the predicted family value also known as genetic gain (G) as: $G = h^2S$, where S is selection differential or deviation from trial mean (Ofori et al., 2007).

Results

Attack

Orygmophora shoot borer attack was recorded at all the three sites four months after the establishment of the plots. However, incidence of attacks were generally low and not statistically significant among progenies or across sites. After 12 months, attack rates were largely unchanged at the moist and dry forest sites, while only marginal increase in attack was recorded at the wet site. After 20 months (1.7 years), differences in the incidence of attack began to show among progenies, sites, and between the interaction of progeny and site (Table 2). Across progenies, attack was generally lower at the wet site than at either the dry or moist sites (Figure 1). Progenies with low in-

Table 2. Results of two-way analyses of variance of *Orygmophora mediofoveata* shoot borer attack, percent survival, height and diameter of 15 *Nauclea diderrichii* progenies established in three forest zones in Ghana.

	Sources	F	P
Attack*	Site	102.37	<.0001
	Progeny	1.53	0.0945
	Site* progeny	1.95	0.0022
%survival	Site	12.240	<.0001
	Progeny	2.05	0.0183
	Site* progeny	1.12	0.3283
Height	Site	335.22	<.0001
	Progeny	1.87	0.0254
	Site* progeny	0.75	0.8217
Diameter	Site	153.05	<.0001
	Progeny	2.46	0.002
	Site* progeny	1.14	0.2835

*Assessment carried out at 1.7 years.

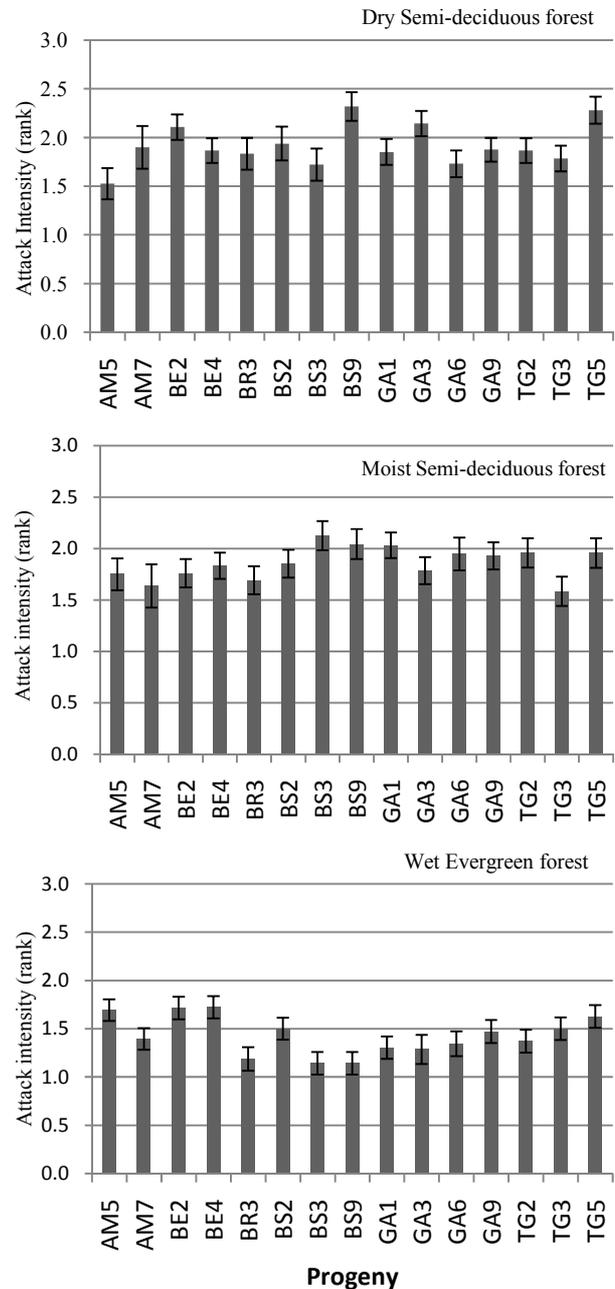


Figure 1. *Orygmophora mediofoveata* shoot borer attack of 15 *Nauclea diderrichii* progenies 1.7 years after planting in three forest zones in Ghana.

cidence of attack at the wet site were BR3, BS3 and BS9, while TG5, AM5, BE2 and BE4 sustained significantly higher incidence of attack. At the dry forest site, AM5, BS3, GA6 and TG3 experienced lower incidence of attack while TG5, GA3 and BS9 recorded higher rates of attack. However, incidence of attack did not vary significantly among progenies at the moist site.

Survival

The survival rates of seedlings were generally high for all 15

progenies and at all three sites four months after planting ($P > 0.05$). Overall survival across progenies was 96.3% at the wet-site, 90.3% at the moist site and 88.8% at the dry site. However, differences in survival rates were observed among sites and among progenies at plantation age 2.7 years (**Table 2**). Mean percent survival was significantly higher at the wet site (79.5%) compared to the moist (50.8%) or dry (55.0%) forest sites. Average overall survival across all three sites was 61.7%. At the wet site, all except AM7 recorded higher than average percent survival. At the dry site, five progenies (BE2, BE4, GA1, GA9 and TG2) were higher than average. However, only two progenies (BE2 and GA3) recorded higher than average percent survival at the moist site (**Figure 2**).

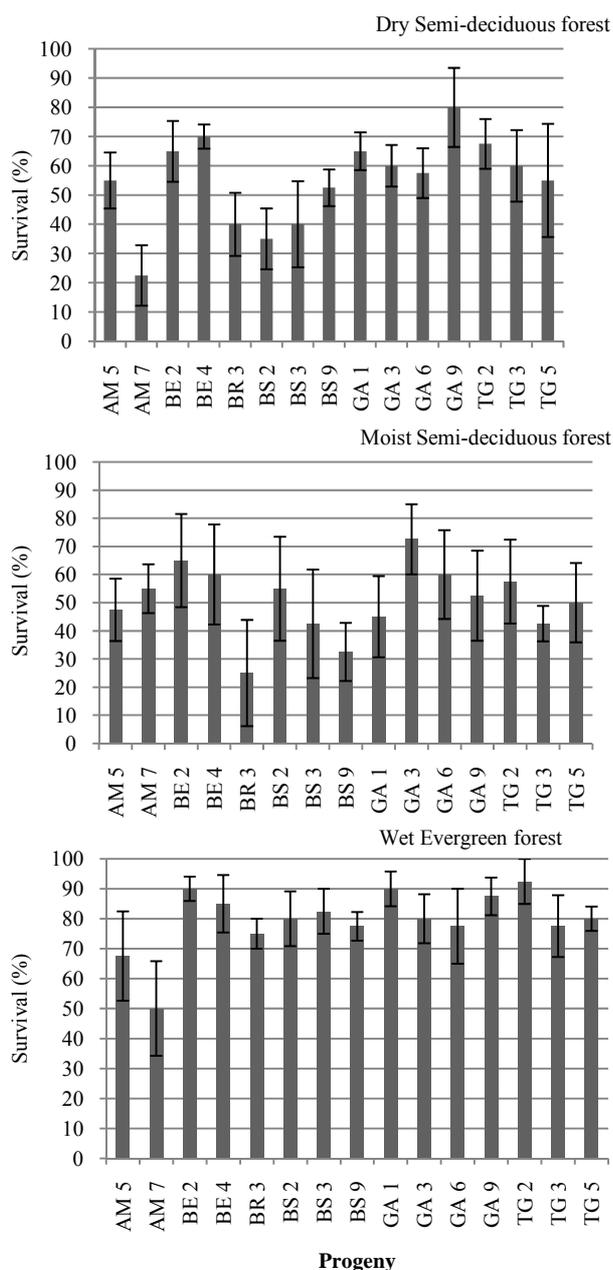


Figure 2. Percent survival of 15 *Nauclea diderrichii* progenies 2.7 years after planting in three forest zones in Ghana.

Growth

Height: Significant differences in mean height were observed among progenies, sites, and the interaction of progeny and site in the early stage of the plantation (4 months). Across progenies, mean height was significantly higher at the wet site (39.40 ± 1.12 cm) compared to the moist (22.57 ± 0.61 cm) or dry (24.55 ± 0.23 cm) forest sites. Within sites, however, height varied only at the moist ($F = 6.129$, $P < 0.0001$) and dry ($F = 5.413$, $P < 0.0001$) sites.

At one year, differences in height were observed among progenies, sites, and between the interaction of progeny and site (**Table 2**). Mean height across all 15 progenies was highest at the wet site (74.62 ± 4.11 cm), followed by the dry site (57.40 ± 3.14 cm), and the moist site (34.43 ± 2.96 cm). Mean differences in height of the 15 progenies varied somewhat randomly, from site to site. The pattern in height growth observed during the 4th and 12th months remained largely unchanged at the last assessment (age 2.7 years), although by this time the progeny-progeny differences were not significant at any of the three sites. Mean height across sites were; wet (540.34 ± 6.20 cm), dry (430.05 ± 7.83 cm), and moist (273.11 ± 8.17 cm). At age 2.7 years, the following progenies were among the fastest growing in the plots: wet site (BS2, BS3, BS9 and TG2), dry site (AM7, BS2, and BS9), and moist site (BS9, BS3, and GA3) (**Figure 3**).

Diameter

Diameter of seedlings measured 10 cm from above the soil level after one year varied significantly among sites. Mean diameter was 1.43 ± 0.02 cm at the wet site, which was significantly higher than that at the moist (1.16 ± 0.28 cm) or dry (0.92 ± 0.27 cm) forest sites. A similar trend was observed when diameter was measured at breast height (dbh = 1.3 m) at age 2.7 years (**Figure 4**). Mean diameter was highest at the wet site (5.31 ± 0.21 cm), followed by the dry site (4.58 ± 0.30 cm) and moist site (2.83 ± 0.32 cm). All progenies except BR3 recorded high growth in diameter at the wet site. At the dry site, AM5, BE2 and BR3 recorded relatively low growth in diameter. Three progenies BS3, BS9 and GA1 recorded moderately higher diameter growth than the others at the moist site.

Heritability and Genetic Gain in Height at the Moist Semi-Deciduous Forest Zone

Heritability for total height at the Moist Semi-deciduous Forest Zone was 0.438, indicating that approximately 44% of the variation observed in height growth at the MSF site was under genetic control. The variation in genetic gain from the site ranged from 28.36% (BS9) above mean performance to -20.08% (TG 5) below mean performance (**Table 3**).

Discussion

Shoot Borer Damage

None of the 15 progenies assessed escaped *O. mediofoveata* attack during the period of the study. In other words, none exhibited complete resistance or immunity to the shoot borer. However, it was clear from the results that significant variability to *O. mediofoveata* shoot borer attack occurs among the progenies, which were strongly influenced by habitat or site factors. While infestation was recorded at all the three sites during

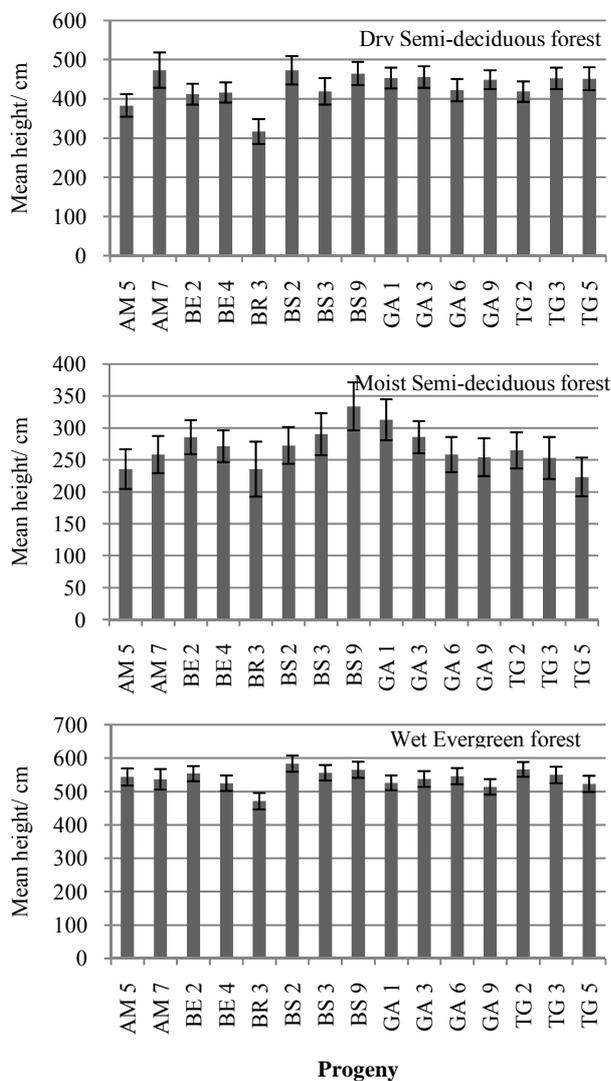


Figure 3. Mean heights of 15 *Nauclea diderrichii* progenies 2.7 years after planting in three forest zones in Ghana.

assessment in the fourth month, it was not until the 20th month that clear-cut differences were noticed. For example, while attacks were marginally lower at the Moist Semi-deciduous and Dry Semi-deciduous Forest zones at the 4th and 12th month, the reverse was observed during the peak of the infestation at 20 months. The higher initial attacks at the Wet Evergreen Forest zone might be due to the presence of an older *N. diderrichii* plantation established in 1972 and located at about 100 m away from the experimental plot. This plantation was very likely the source of *O. mediofoveata* population which facilitated an early colonization of the plots at the WEF site as compared to the remaining two sites.

Shoot borer attacks were observed in the plantation after the peak infestation at 1.7 years, however, the impact of the attack did not show on the trees. The occurrence of fresh attacks were evident but visually this did not appear to substantially impact on the growth of the plant. This is quite contrary to the situation with, for example, the mahogany shoot borer (*Hypsipyla robusta*) attack which is a serious pest of species of the Meliaceae

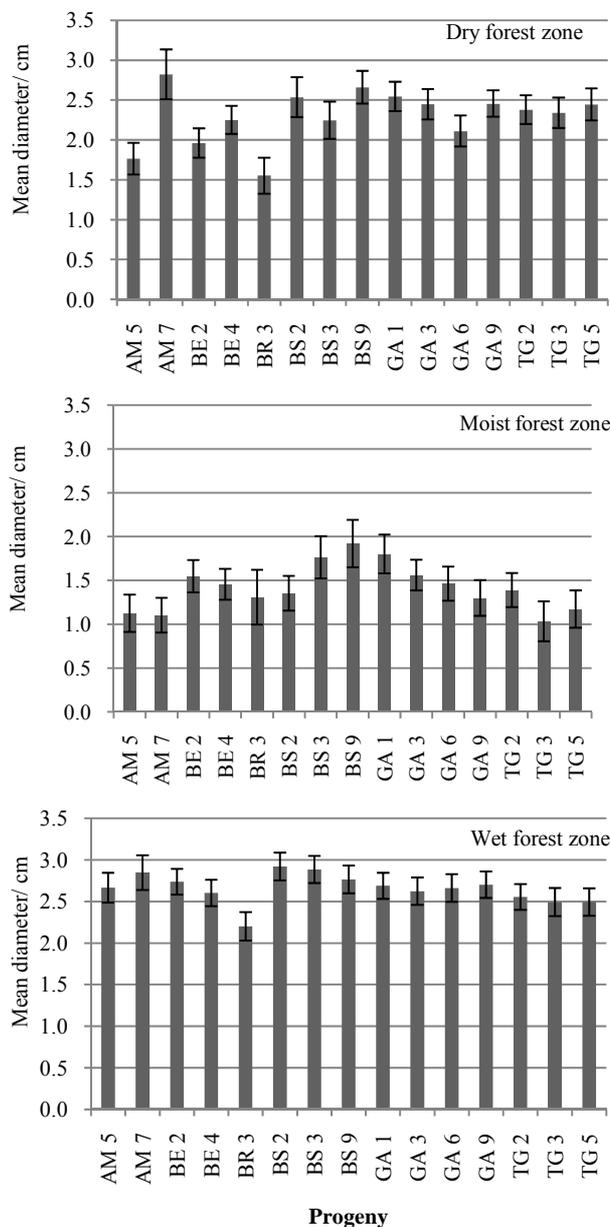


Figure 4. Mean diameter (at breast height) of 15 *Nauclea diderrichii* progenies 2.7 years after planting in three forest zones in Ghana.

in Ghana and many tropical countries (Ofori et al., 2007, Opuni-Frimpong et al., 2008; Bosu & Nkrumah, 2011). *Orygmophora mediofoveata* damage did not cause *N. diderrichii* to develop profuse epicormic branching as is often the case with *H. robusta* attack of the Meliaceae. Although epicormic branches occurred in some cases, there was usually a clearly distinguishable lead terminal that suppressed the growth of the remaining shoots as the tree grew. The worst case scenarios recorded in the plantation were just a dominant stem and a smaller or poorly growing stem. In general, the damage levels observed did not cause significant mortalities to the seedlings. Healthy and vigorously growing seedlings tended to recover (coppice) from attack and subsequent dieback (withering of the shoot) when growing conditions were optimum, thus mortality

Table 3. Selection differential and genetic gain in total height growth (cm) for 15 *Nauclea diderrichii* progenies at Mesewam nursery in the Moist Semi-deciduous Forest zone.

Progeny	Mean height	Deviation	% Deviation	% gain	Rank
BS 9	333.62	3.34	24.020	28.36	1
GA 1	312.78	3.13	16.274	19.21	2
BS 3	290.29	2.90	7.916	9.34	3
GA 3	285.69	2.86	6.204	7.32	4
BE 2	285.58	2.86	6.162	7.27	5
BS 2	272.50	2.73	1.301	1.54	6
BE 4	271.37	2.71	0.880	1.04	7
TG 2	265.00	2.65	-1.487	-1.76	8
AM 7	258.41	2.58	-3.937	-4.65	9
GA 6	258.33	2.58	-3.965	-4.68	10
GA 9	254.05	2.54	-5.558	-6.56	11
TG 3	252.94	2.53	-5.970	-7.05	12
AM 5	235.63	2.36	-12.404	-14.64	13
BR 3	235.50	2.36	-12.454	-14.70	14
TG 5	223.25	2.23	-17.007	-20.08	15

due to *O. mediofoveata* shoot borer attack was lower than expected.

However, the impact of the damage to *N. diderrichii* seedlings at the nursery stage appeared much higher and devastating than were observed in the field. It appears that bigger and sturdier seedlings used for outplanting in the field make the seedlings more tolerant to shoot borer damage than smaller and more tender seedlings that are frequently attacked at the nursery. By maintaining seedling vigour, minimizing shock during transportation from the nursery to field sites, and planting at the beginning of the rainfall season (April-May), the impact of *O. mediofoveata* attack could be substantially reduced in plantations.

Survival

The percentage survival of 88.8% - 96.3% recorded four months after establishment is encouraging for a native timber species growing under pressure of its primary insect pest. In a study to evaluate the growth of *N. diderrichii* in pure and mixed species trials conducted at the BiaTano Shelterbelt forest reserve in Ghana (Moist Semi-deciduous Forest zone), Addo-Danso et al. (2012) recorded an initial (after 6-month) survival of 70.8% in monoculture plots, 63.0% in a two-species mixed plots, and 38.9% in a 4-species mixed plots. In the same study, overall survival of *Nauclea* in the plantation was 40% in the monoculture after 24 months (2 years) and remained largely unchanged after 36 months (3 years). Compared to the present study, survival of the worst performing progenies were better than those reported by Addo-Danso et al., (2012).

Growth

As *Nauclea* is a wet/moist forest species, we expected that overall performance (resistance to attack by the shoot borer, survival, and growth rates) of the progenies would be better at the wet (WEF), followed by the moist (MSF) site, before the dry (DSF) zones. Our hypothesis was partially supported, in that performance was better at the WEF. However, between the moist and dry forest zones, average performance was better at the DSF site than the MSF site (Table 4). It seems that the poor survival and growth at the MSF was due largely to poor site factors that prevailed in the location where the plots were established. Besides, having been heavily cropped for many years, the soil in this location was mostly clayey and liable to flooding during periods of heavy rainfall.

Differences in growth (height and diameter) were recorded at various stages, however, at the last assessment at age 2.7 years, progenies BS9, BS3, BS2 and GA1 were among those with the highest overall height and diameter growth rates in the plantations. However, the Bensoprogenies (BS9, BS3 and BS2) were also those with the lowest overall survival rates among the 15 progenies. Perhaps, the high level of mortality afforded the surviving seedlings less competition for growth. The growth rates achieved under the present study compares favourably well with previous studies of *Nauclea* in Ghana and elsewhere in West Africa. In Ghana, Addo-Danso et al., (2012) recorded overall height growth of 1.9 m in monoculture *Nauclea* plots at the Bia-Tano shelterbelt after 24 months, 2.8 m at 36 months and 6.8 m at 60 months. The corresponding diameters of these heights were 3.8 cm, 4.1 cm and 9.7 cm, respectively. It is worth noting that all 15 progenies assessed in this study achieved a mean height of more than 3.5 m and diameter more than 3.5 cm at 32 months (2.7 years), both of which are greater than what was achieved at 36 months by Addo-Danso et al., (2012). Heights and diameter in mixed plots were lower than in the monoculture plots. In Nigeria, Onyekwelu (2007) reported a mean total height of 9.0 m height and diameter of 9.6 cm for a 5-year old *Nauclea* plantation in the Omo forest reserve. Mean tree diameter at breast height (dbh), total height and standbole volume ranged from 9.6 to 29.3 cm; 9.0 to 23.6 m and 23.27 to 535.52 m³/ha, respectively from plantations ranging from 5 - 30 years of age. Also in Nigeria, Fawape et al., (2001) recorded mean height of 14.07 m and 0.29 m dbh in a 20-year-old even-aged stand of *Nauclea diderrichii* in the Akure forest reserve located in the humid rainforest zone of Ondo State.

Conclusion

None of the 15 progenies was distinctly different from the others in any measure during the entire evaluation period. Rather, site-site differences were clear. It appears therefore that good or suitable site factors, especially the soil and water, are the important factors to be considered when establishing plantations of *N. diderrichii*. It will be important to ensure that seedlings used are sturdy and the plantation is properly managed. In addition, it is also important that progenies planted are not far away from the ecological zones where they were obtained, such as planting Dry Semi-deciduous progenies in the Wet Evergreen Forest zone and vice versa.

The low growth rate recorded at the Mesewam nursery area (MSF) though unexpected provided insight as to which of the progenies could be best suited for planting under harsh or

Table 4.Mean overall performance of 15 *Nauclea diderrichii* progenies established in three forest zones in Ghana at 2.7 years.

Site	Height \pm S.E (cm)	Diameter \pm S.E (cm)	Survival \pm S.E (%)	*Attack \pm S.E. (rank)
Dry Semi-deciduous forest zone DSF (Abofour)	430.78 \pm 7.8 a	14.38 \pm 0.34 a	55.00 \pm 3.09 a	1.92 \pm 0.03 a
Moist Semi-deciduous forest zone-MSDF (Mesewam)	273.28 \pm 8.1 b	8.93 \pm 0.35 b	50.83 \pm 3.68 a	1.86 \pm 0.03 a
Moist/Wet Evergreen forest zone (Benso)	540.20 \pm 6.2 c	16.67 \pm 0.67 a	79.50 \pm 2.44 b	1.44 \pm 0.01 b

*Based on assessment carried out at 1.7 years.

stressed environmental conditions. As observed (**Table 3**), the Benso, Gambia and Begoro progenies were the most suitable under the prevailing poor soil condition. Indeed, the Benso (WEF) progenies BS9, BS3 and BS2 came close to what may be described as best performing progenies of the study. These progenies were obtained from an existing *N. diderrichii* (establish in 1972) plantation located in the Nueng Forest where wet forest zone trial was conducted. The origin of the 1972 plantation is unknown, but it appears that they were carefully selected for planting.

We recommend that the following progenies BS9, BS3, BS2, GA1, GA3 and BE2 should be considered for plantation establishment. With the distribution range of *N. diderrichii* spanning across the African continent, it is recommended that future studies should consider a range-wide progeny and provenance assessments.

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